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Effect on composition of calciphile plants when grown in soil media containing calcium hydroxide, calcium sulphate, and calcium sulphate plus sodium hydroxide.

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EFFECT ON COMPOSITION OF CALCIPHILE PLANTS WHEN GROWN IN SOIL MEDIA CONTAINING CALCIUM HYDROXIDE, CALCIUM SULPHATE, AND CALCIUM SULPHATE PLUS SODIUM HYDROXIDE

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EFFECT ON COMPOSITION OF CALCIPHILE PLANTS
WHEN GROWN IN SOIL MEDIA
CONTAINING
CALCIUM HYDROXIDE, CALCIUM SULPHATE, AND
CALCIUM SULPHATE PLUS SODIUM HYDROXIDE

by

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I. INTRODUCTION

From the scientific point of view now that so much fundamental work on the ion uptake of plants has been done by plant physiologists, the most promising method is: first, the study of the plants under conditions that are strictly defined and controlled; and second, with this data determined, try to propound with the aid of past physiological work. Suffice to say that work with plants and soils is easily vitiated by factors which are beyond control.

The soil from an agronomic view point is a dynamic system subject to manifold chemical, physical and biological processes. In this connection it is indeed helpful in the study of plant relations to soil to ascribe a set of rather narrow limits to the investigation.

So it is, then, that soil acidity , or what is sometimes called lack of lime, should be an ideal approach to a scientific study of plants. This pH variable in relation to growth of plants is very complex and one has but to scan the literature to encounter the work of numerous soil workers. Beginning with Wheeler at the Rhode Island Experiment Station, in the closing years of the 19th century, a rapid development on the part of the farmer for the need and value of lime in agriculture is evidenced.

The problem, as it presents itself today, is a little more confusing. The question has arisen as to how the soil reaction influences growth.

The point is that we do more than add calcium to the soil as a plant nutrient. A set of equilibria are upset which influence the physical condition of the soil, the solubility of toxic compounds, activity of micro-organisms, availability of essential elements and prevalence of plant diseases.

The following work was carried out along two lines: first, greenhouse experiments with different crops and a single soil type to determine whether or not any relation exists between crop response and changes induced in the soil by the addition of calcium hydroxide, gypsum and a mixture of gypsum and sodium hydroxide; and second, laboratory work to determine the amount of calcium, magnesium and iron contained in the plant tissue.

REVIEW AND DISCUSSION OF LITERATURE

Naftel (1), in his work with Norfolk, Hortsells and Cecil sandy loams, shows that the percentage of calcium in the sorghum plants were increased very greatly by the addition of calcium carbonate. Also it was seen from the data that the magnesium content of sorghum was quite low in the plants from the high calcium saturated soils.

According to Pitz (2), calcium sulphate, when added to the soil, produced no marked increases in nitrification or ammonification. Root development, however, was increased by calcium sulphate 0.01 per cent, being apparently as efficient in producing this increase as 0.1 per cent.

Erdman (3), in an extensive experiment on the reaction of the soil with calcium sulphate, shows that gypsum added in amounts from 1,000 to 2,000 pounds per acre to an acid soil, a neutral soil and a basic soil did not increase or correct the acidity of the soil as shown by the Tacke lime-requirement method. Gypsum applied at the rate of 100, 200 and 500 pounds per acre did not raise or lower the hydrogen-ion concentration of the soil as measured by the hydrogen electrode.

With pot experiments on rice, Gile and Carrero (4) showed that calcium sulphate increased the percentage of calcium in the plant ash. However, calcium sulphate did not induce iron chlorosis, but additions of calcium carbonate showed severe chlorosis which was associated with a depression of iron in the plant ash.

Parker and Pate (5), in their work on exchangeable calcium, report that the availability of the exchangeable bases in a soil may not have an important influence on the physical properties of the soil, but it is probable that it is of importance in the nutrition of plants. They conclude that the exchangeable calcium in soils having a high hydrogen-ion concentration has a low availability, while the availability of calcium in non-acid soils is high.

Neidig, McDole and Magnuson (6), working with pot experiments on six principal soil types of Idaho, found that applications of 200 pounds of gypsum per acre produced increases over check in total dry weight of alfalfa. These increases over the check amounted to 1.5 per cent with Boise silt loam to 79.2 per cent for Palouse soil loam.

Another type of experimentation which undoubtedly has a decided influence upon the absorption of mineral nutrients is the analysis of the leachings for lysimeters.

MacIntire, Shaw and Young (7) secured results with calcium, and magnesium leachings from 46 lysimeters over a eight-year period. When calcium carbonate equivalent to eight tons of calcium oxide per 2,000,000 pounds of soil are added to an acid loam, the average annual loss of magnesium from the calcium carbonate treated soil was 81 pounds as compared with 106 pounds from the untreated.

Bryan (8), while working with plants grown in quartz cultures in the greenhouse, draws attention to the fact that "the greater the acidity of the media in which the plants are grown, the less power have the plants to obtain the basic substance calcium for metabolic processes."

Carolus (9) found that the magnesium oxide content of potatoes was decreased with applications of calcium hydroxide. The soil at the start of the experiment was deficient in magnesium. An application of 2,000 pounds of calcium hydroxide showed the magnesium oxide content to be 0.59 per cent, while that of the untreated plot was 0.83 per cent.

From experiments to determine how calcium carbonate and calcium sulphate affect the water-soluble iron, calcium, magnesium, potassium, sulphur and phosphorus in soils, determined by ordinary water extractions, Lipman and Gericke (10) arrived at the following conclusions:

The soluble magnesium content of all soils studied was increased by calcium carbonate treatment. Magnesium seems to have remained unaffected or even to have been depressed by calcium sulphate treatment in all but one case. The soluble iron content was increased in the greenhouse soil by treatment with calcium sulphate.

McCool and Mellar (11) in 1920 report an interesting experiment on the effect of calcium sulphate on the solubility of soils. Six soils, widely different in texture, were mixed with gypsum and washed with water until the freezing point lowering of the filtrate was negligible. The soils were allowed to stand for 30 days at a high water content. At the end of the thirty-day period, the soils were again washed and a freezing point determination made on the filtrate.

With the gypsum-treated soils, there was a marked depression in the freezing point over the control. If the differences in freezing point are taken as an index of the amount of soluble substances in solution, then calcium sulphate has a solvent action on soils.

Using the dry weight of barley in grams as an index, Hartwell and Damon (12) showed that applications of calcium carbonate and calcium sulphate added in equivalent amounts to soils, resulted in extreme differences in weight. With no lime added, the dry weight was 3.9 grams; with calcium carbonate, it was 52 grams; and when calcium sulphate was added, the dry weight was only 4.6 grams.

The literature pertaining to the effects of acid soil on plant growth is very extensive. Therefore just those papers will be reviewed that are pertinent to the question at hand.

It is a well-known fact that lime improves the physical and biological conditions of soils. (13).

The work of Hoagland (14) indicates that a direct toxic effect upon root tissues does not take place except with extreme acidity or alkalinity. The reaction of the root saps were made and showed that the pH range varied from 4 to 6. This indicates that plant tissues can stand acidities found in ordinary soils.

Using a Dunkirk gravelly sandy loam, Mann (15) found the solubility of iron was increased by moderate liming, but decreased at the higher rates (3 to 6 tons). No significant differences were found in the effects of liming on iron absorption.

In an extensive review of the nature of soil acidity, Truog (16) states that the supply of available calcium in all forms becomes less as soils become acid, but usually there is still sufficient calcium present to furnish that needed as direct food material.

In summarizing the work of Gile and Ageton, Willis (17) states, "There is strong evidence that the deficiency of iron occasionally noted when soils are limed is partly induced by a disturbance in the physiology of plants, and in the face of this it is impossible to determine to what degree the effect of lime has on the solubility of iron."

Shear (18) studied the effect of soil reaction using a Clarksville silt loam. The amount of iron found in castor bean and cosmos was increased with increased acidity. African marigold showed a reverse relationship.

DISCUSSION OF LITERATURE

There is indeed a marked disparity throughout the literature in respect to scientific investigations along soil-plant relationships. These apparent disagreements are really only manifestations of the marked differences "characterizing the physical-chemical systems which are called soils in equilibrium with water."

Soils are considered dynamic and not static in nature and when we include base exchange, colloidal systems and absorption, it is not difficult to understand discrepancies in the reactions between different soils and calcium hydroxide or calcium sulphate, which are the treatments in this thesis.

With this conception as a basis, the conflicting statements in the literature on the effect of calcium carbonate and calcium sulphate and on the uptake of magnesium and iron may be accounted for by the conditions present in the soil at the time of the experiment.

METHOD OF EXPERIMENTATION

A very acid Cheshire sandy loam (pH 4.5) was obtained and brought into the greenhouse where it was dried. This soil is from the less productive lands of the hill region along the Connecticut Valley. It is weathered from glacial till and is characterized by a brown surface soil, reddish-brown subsoils, and pink or red substrata. After sifting, to remove the roots and stones, eight pounds of air-dried soil was put into one-gallon earthenware crocks.

To determine how much calcium hydroxide would be necessary to change the original pH 4.5 to pH 7.5, a series of eight crocks of soils were set up and varying increments of calcium hydroxide added. The soils were watered and a week was allowed for the soils to come to equilibrium, at which time they were tested for pH by the Beckman potentiometer. It was found that 24 grams of C. P. calcium hydroxide was necessary to bring the soil to a pH of 7.5.

The plants were selected on the basis of their lime-loving characteristics, and flowers, grasses and vegetables were included to make an arbitrary division. The following kinds of plants were used in making the studies:

Flowers

Chrysanthemum
Carnation
Dianthus

Grasses

Barley
Timothy

Vegetable

Endive

Four series of soils, in duplicate, were set up and amounts of soil amendments added as follows:

	Treatment	pH	Amount per Crock
Series I	Check	4.5	
Series II	$CaSO_4$	4.5	47.1 grams C. P.
Series III	$Ca(OH)_2$	7.5	24.0 grams C. P.
Series IV	$CaSO_4$ & NaOH	7.5	47.1 grams $CaSO_4$ & 1 gram NaOH

An equivalent amount of calcium was present in Series II and Series III. Series IV is designed to raise the pH to 7.5, as the uptake of ions is contingent on the pH of the soil solution.

A basal fertilizer treatment was applied to all the soils consisting of:

1.27 grams Urea
2.45 grams KH_2PO_4
0.658 grams KCl

These fertilizers and salts were mixed thoroughly by means of a rotary hand mixer, and the soil kept moistened for two weeks before the seedlings were transplanted.

The seeds were planted in flats in a favorable soil medium in the greenhouse. When the weather became favorable they were placed outside until the seedlings were large enough to plant.

Growing the seedlings in a circumneutral soil and then transplanting them to soils with various reactions has a few disadvantages, which in this type of experiment would seem to be outweighed by other factors. An attempt was made, however, to start the seed directly in the soils, but the severe treatment showed itself in the growth and vigor of the seedlings. The seeds were finally given a favorable start in a friable garden soil and later transplanted to the treated soils. The same number of seedlings were transplanted to each crock.

The crocks were placed in carts in the Experiment Station Greenhouse. The plants were grown, therefore, under out-door conditions, but could be rolled into the greenhouse if sudden storms arose. The crocks were submerged in wet sawdust to prevent the soil from heating and excessive evaporation.

The crops were carefully watered during the summer and, as each type of plant came to maturity, it was cut at the junction of shoot and root. The soil adhering to the roots was carefully washed off. After drying the plant material in an oven, separate weighings of both root and shoot were made. Preparation of the plant material, prior to analysis, was made by grinding in a Wiley mill.

The plant material was ashed according to the wet ash method.

Five grams of material (19), in duplicate, was carefully weighed and introduced into a 500 cc. short-necked Kjeldahl flask, 20 cc. of concentrated sulphuric acid was added and the contents thoroughly mixed. Glass beads were added to prevent bumping. Concentrated nitric acid was slowly dropped into the flask by means of a separatory funnel. When there was added an amount of acid sufficient to make the contents of the flask liquid, a medium flame was applied. The dropping of nitric acid was stopped and the flask was heated until white fumes of sulphur trioxide appeared. Nitric acid was continued dropping until the plant material was completely oxidized and the liquid in the flask clear. The nitric acid dropping was then discontinued and the flask heated until white fumes of sulphur trioxide came off.

The last traces of nitric acid were expelled by dilution with distilled water and once more heating until white fumes appeared.

The flasks were allowed to cool, and the contents diluted with water. The flasks were shaken frequently during a period of standing for at least an hour, in order to insure solution of all calcium sulphate. The diluted ash was then filtered through 9 cm. filter paper (C. S. & S. 602) into a 250 ml. volumetric flask. The flask and paper were washed thoroughly and the whole brought to volume.

PROCEDURE FOR THE DETERMINATION OF READILY AVAILABLE CALCIUM IN PLANTS (20)

50 cc. aliquot duplicates of the diluted ash, corresponding to 1 gram of plant material, were drawn and placed in 250 cc. beakers. Two drops of phenol red was added, and concentrated ammonium hydroxide, drop by drop, until the solution was pink. With sulphuric acid (1-1) the solution was made acid (yellow). Five cc. of N/5 sulphuric acid and 10 cc. of 2.5 per cent oxalic acid was added and the solution heated to boiling. Twenty-five cc. of 4 per cent ammonium oxalate was added and the solution again brought to a boil. The mixture was put on a hot plate, below boiling, for one-half hour and stirred occasionally; then allowed to stand

overnight. The liquid was filtered through a Gooch crucible and the precipitate washed several times with a o.5 per cent solution of ammonium oxalate, and five times with distilled water.

The Gooch and precipitate were placed into a 250 cc. beaker and 20 cc. of hot 3N sulphuric acid was added to dissolve the calcium oxalate precipitate. Fifty cc. of hot water was added and the solution heated to 90° C. Potassium permanganate N/50 was used for titration.

PROCEDURE FOR THE DETERMINATION OF READILY AVAILABLE MAGNESIUM IN PLANTS.

The filtrate obtained from the calcium precipitation was heated to nearly boiling, and 1 cc. of concentrated ammonium hydroxide was added. Twenty cc. of 8 hydroxyquinoline solution (1.25 per cent) and 4 cc. of ammonium hydroxide (concentrated) for 100 cc. of solution was added. The samples were stirred with a mechanical stirrer for 15 minutes.

The precipitate was allowed to settle overnight. The mixture was filtered through a Gooch crucible and washed with hot, dilute ammonium hydroxide (1:40) and six times with distilled water.

The Gooch was placed in a 400 cc. beaker and the precipitate dissolved by pouring two 50 cc. portions of hot dilute hydrochloric acid (1:9). Fifteen cc. of concentrated hydrochloric acid and about 100 cc. of distilled water was finally added.

Twenty-five cc. of standard potassium bromate-bromide was added, and immediately 10 cc. of potassium iodide solution was also added. The solution was titrated with standard sodium thiosulphate solution and two to three cc. of starch solution added as an indicator.

The reactions involved in the titration are as follows: hydrochloric acid reacts with the potassium bromate-bromide solution liberating free bromine; the free bromine reacts with the 8 hydroxyquinolate in solution forming dibromo-hydroxyquinolate. On addition of the potassium iodide solution, the excess of free bromine is replaced by free iodine which is titrated with standard solution of sodium thiosulphate.

THE DETERMINATION OF IRON IN MINUTE AMOUNTS

A stock solution of iron was made by dissolving a 0.1 gram of anslytical iron wire in 100 cc. after the addition of 3.0 cc. of nitric acid.

A 0.1 gram of plant material, in duplicate, was carefully weighed and transferred to a 100 cc. Kjeldahl flask. 10 cc. of sulphuric acid (1-1), 3 cc. of 60 per cent perchloric acid and a glass bead was added, and the mixture brought to a boil over a microburner. The digest was boiled until it became colorless. The mixture was cooled and transferred to a 50 cc. graduated flask. A blank determination for error in reagents was carried on simultaneously.

An aliquot of 10 cc. was pipetted into a 50 cc. glass-stoppered cylinder and distilled water was added to bring the volume to 15 cc. Then 0.5 cc. of 4 per cent potassium persulphate and 10 cc. of a mixture, of one part of ethylene glycol monobutyl ether and one part of ethyl ether, were added in the given order. Finally 5 cc. of a 10 per cent potassium thiocyanate was run in. The contents of the cylinders were thoroughly shaken and allowed to stand for five minutes.

By means of 2 cc. pipettes, a portion of the ethereal layer was quickly transferred to the cup of a Bausch and Lomb microcolorimeter for comparison.

It was found most convenient to manipulate six cylinders at a time, four cylinders of test solution and two cylinders of freshly-prepared standards. The subsequent steps for making the standard solutions were carried out precisely as described above.

PRESENTATION AND DISCUSSION OF EXPERIMENTAL DATA

Since the acidity of a soil is due to the presence of hydrogen ions, it is logical that the effect of these ions on growth should be given first consideration.

It is well to state at this point that plant growth is not related to hydrogen-ion concentration as such in soils, but rather to the indirect effects that soil acidity produces on the chemical and biological conditions of the soil.

When plants are grown in solution cultures and supplied with nutrients, the reaction of the solution can be controlled and made the limiting factor.

In this type of experiment where soil is the growing medium, and excess amounts of calcium are added, the pH factor on growth is obscured by the extreme treatment. Therefore, the effect of reaction on plant growth will be omitted from the discussion. The effect of pH on the ions absorbed by the plants roots, however, will be discussed.

EFFECT OF TREATMENT ON TOTAL DRY WEIGHT OF PLANTS

Table I gives the treatment and responses of the plants in grams on a dry weight basis. The soil in Series I was untreated and designated as the Check. In Series II, 47.1 grams of calcium sulphate was added to the soil. The hydrogen-ion concentration in Series I and II was about 4.5. Twenty-four grams of calcium hydroxide was added to Series III. In Series IV, 47.1 grams of calcium sulphate plus 14.0 grams of sodium hydroxide were added to the soil. By the addition of the sodium hydroxide, to Series IV, the hydrogen-ion concentrations of Series III and IV were about 7.5 at the start of the growing period.

Table I.

Total Dry Weights of Plants

	Series I. Check	II. $CaSO_4$	III. $Ca(OH)_2$	IV. $CaSO_4$ NaOH
Chrysanthemum..	46.6 gms.	36.9 gms.	20.1 gms.	--
Carnation......	47.6	58.5	41.6	--
Barley.........	21.4	36.0	40.0	28.8
Dianthus.......	31.2	30.0	16.3	--
Endive.........	5.0	59.3	85.2	36.2
Timothy........	6.8	31.5	17.5	9.6

Chrysanthemem and Dianthus shows increased dry weight in grams over the other treatments when grown in the check crocks. Calcium sulphate produced best growth for Carnation and Timothy, while Barley and Endive showed response in the calcium hydroxide crocks. This variation is probably due to the individual plant preference for the sulphate and hydroxide ions. The author can give no apparent reason for the increase in growth of Chrysanthemem and Dianthus over the other treatments. The latter, however, exhibited only a very slight weight in excess of the calcium sulphate treated soil.

The calcium sulphate plus sodium hydroxide series was added to the thesis to compare the uptake of ions, especially iron, from the acid calcium sulphate soils and the more basic calcium sulphate plus sodium hydroxide treated soils. Comparing these two treatments, it is found in Table I that the dry weight in Series IV is smaller than in Series III, but in every case larger than the check soils.

It is evident that the addition of the sodium ion to Chrysanthemem, Carnation and Dianthus was too toxic for the growth of those plants.

The author can give no reason for the apparent increase in dry weight of Chrysanthemem and Dianthus in the check soils over the other treatments.

CHRYSANTHEMUM AS AFFECTED BY SOIL AMENDMENTS

pH:	6.29	4.38	4.54
$CaSO_4$ NaOH	$Ca(OH)_2$	$CaSO_4$	Check

Table II shows the differences in grams of dry material from the aerial portions of the plants.

Table II.

Dry Weight of Plant Tops

	Series I. Check	II. $CaSO_4$	III. $Ca(OH)_2$	IV. $CaSO_4$ NaOH
Chrysanthemum..	38.0 gms.	30.1 gms.	16.5 gms.	--
Carnation......	37.5	46.3	35.7	--
Barley.........	17.0	27.5	29.5	23.0
Dianthus.......	24.9	28.0	10.3	--
Endive.........	2.2	23.8	50.5	22.8
Timothy........	4.9	21.4	11.4	7.5

The calcium sulphate treatment shows increased growth for Carnation, Dianthus and Timothy. This increase seems to be attributed to the sulphate ion because it was pointed out in the experimental data that the same amount of calcium was applied to Series II and III. The pH is not the limiting factor as evidenced by the fact that the check soils produced more growth than the calcium hydroxide treated soils, except in the case of Timothy. Barley and Endive made more top growth in the neutral calcium hydroxide treated soils, and Chrysanthemum increased with the check soils over the other series.

CARNATION AS AFFECTED BY SOIL AMENDMENTS

pH:	6.60	4.82	4.60
$CaSO_4$ $NaOH$	$Ca(OH)_2$	$CaSO_4$	Check

Table III.

Dry Weight of Plant Roots

	Series I. Check	II. $CaSO_4$	III. $Ca(OH)_2$	IV. $CaSO_4$ NaOH
Chrysanthemum..	8.6 gms.	6.8 gms.	3.6 g.	--
Carnation......	10.1	12.2	5.9	--
Barley.........	4.4	8.5	10.5	5.8
Dianthus.......	6.3	2.0	6.0	--
Endive.........	2.8	35.5	34.7	13.4
Timothy........	1.9	10.1	6.1	2.1

Table III shows the dry weight in grams of the root portions of the crops.

Chrysanthemum, Endive and Timothy show increases over the other treatments when calcium sulphate was added. This is in agreement with the work of Pitz (2). Chrysanthemum shows increased root growth in the check series, and Barley in the calcium hydroxide treatment.

There seems to be no conformity in results in dry weights in tops, roots, or total dry weight of the plants studied. It is possible that these plants possess soil and cultural differences which would account for the results that were obtained.

BARLEY AS AFFECTED BY SOIL AMENDMENTS

pH: 5.50	6.45	4.34	4.33
$CaSO_4$ NaOH	$Ca(OH)_2$	$CaSO_4$	Check

The tops of the plants were analyzed for calcium. The results are shown in Table IV.

Table IV.

Percentage of Calcium in Plant Tissue

	Series I.		II.		III.		IV.	
	pH	Check	pH	$CaSO_4$	pH	$Ca(OH)_2$	pH	$CaSO_4$ NaOH
Chrys'm..	4.54	0.975	4.38	0.995	6.29	2.52	--	--
Carnation	4.60	0.666	4.82	1.02	6.60	2.08	--	--
Barley...	4.33	0.185	4.34	0.342	6.45	0.734	5.50	0.210
Dianthus.	4.36	1.04	4.63	0.879	6.25	1.564	--	--
Endive...	4.63	1.083	4.65	1.919	6.60	2.870	6.52	1.061
Timothy..	4.56	.185	4.59	.266	6.32	0.549	5.26	0.279

As it would be expected, there is a greater percentage of calcium in all cases in the calcium hydroxide treated plants than in the check plants. This agrees with the work of Naftel (1), Parker and Pate (5), and Bryan (8). More interesting, however, is the relation between the calcium sulphate and the calcium hydroxide treated plants in respect to the percentage of calcium absorbed. With all plants, the percentage of calcium was greater in the calcium hydroxide series than in the calcium sulphate series. It would seem, from these data, that the element of pH determined the amount of calcium a plant absorbs because the same amount of calcium was applied to these two series.

It was hoped that the addition of sodium hydroxide to series IV, by lessening the soil acidity, would show the influence of pH on the uptake of calcium with reference to the calcium sulphate series. The table shows, however, that the percentage of calcium in the calcium sulphate plus sodium hydroxide series was less than in the calcium sulphate series. It is the opinion of the author that the reason for this low percentage was due to the toxic nature of the sodium ion, resulting in an abnormal physiological condition in the plant.

In the following table, in which the figures are on a percentage basis, only fluctuations of the various minerals on the basis of equal portions of dry weight are compared. However, a comparison is shown in Table V that evaluates growth, considers the total amount of each material removed from the soil by the plants, and aids in a more comprehensive visualization of existing conditions.

<u>Table V.</u>

Total Grams of Calcium Absorbed

	Series I.		II.		III.		IV.	
	pH	Check	pH	$CaSO_4$	pH	$Ca(OH)_2$	pH	$CaSO_4$ NaOH
Chrys'm.....	4.54	.1788	4.38	.1813	6.29	.4573	--	--
Carnation...	4.60	.1199	4.82	.1827	6.60	.3784	--	--
Barley......	4.33	.0336	4.34	.0650	6.45	.1381	5.50	.038
Dianthus....	4.36	.1899	4.63	.1601	6.25	.2832	--	--
Endive......	4.63	.1961	4.65	.3487	6.60	.5298	6.52	.1962
Timothy.....	4.56	.0291	4.59	.0476	6.32	.0987	5.26	.0528

By reference to Table V, it may be seen that in general what applied to the percentage of calcium is also true for total calcium in the plant. In every case, more total calcium was found in the calcium hydroxide treated soils. There was more total calcium in the calcium hydroxide series than in the calcium sulphate series. The grasses, Barley and

Timothy, ran low in calcium; the other more leafy crops, and endive especially, were high.

Table VI.

Percentage of Magnesium in Plant Tissue

	Series I. pH	Check	II. pH	$CaSO_4$	III. pH	$Ca(OH)_2$	IV. pH	$CaSO_4$ NaOH
Chrys'm....	4.54	.286	4.38	.377	6.29	.390	--	--
Carnation..	4.60	.198	4.82	.299	6.60	.098	--	--
Barley.....	4.33	.260	4.34	.149	6.45	.204	5.50	.213
Dianthus...	4.36	.314	4.63	.237	6.25	.170	--	--
Endive.....	4.63	.967	4.65	.348	6.60	.225	6.52	.204
Timothy....	4.56	.135	4.59	.122	6.32	.270	5.26	.020

Chrysanthemum, Barley and Timothy show a greater per cent of magnesium with calcium hydroxide than in the check. This is in agreement with Lipman and Gerick (10). Carnation, Dianthus and Endive, however, show the opposite. This view is upheld by MacIntire, Shaw and Young (7), and Carolus (9). A study of series II and III shows that the percentage of magnesium is increased with calcium hydroxide over calcium sulphate.

The table gives no relation to pH and calcium and the percentage of magnesium in the plants that were analyzed. This may be due to the plants' individual preferences.

DIANTHUS AS AFFECTED BY SOIL AMENDMENTS

pH:	6.25	4.63	4.36
$CaSO_4$ NaOH	$Ca(OH)_2$	$CaSO_4$	Check

When total magnesium is tabulated, it shows again that Barley, Endive and Timothy, in the calcium hydroxide series, absorbed more total magnesium than Carnation, Chrysanthemum and Dianthus, which grew in the calcium sulphate series. When the calcium sulphate and calcium hydroxide treatments are compared, there is found a tendency for more magnesium to be present with nearly neutral soil conditions. This condition is again in accord with the work of Lipman and Gericke (10). In two cases, Chrysanthemum and Carnation showed the reverse.

Table VII.

Total Grams of Magnesium Absorbed

	Series I.		II.		III.		IV.	
	pH	Check	pH	$CaSO_4$	pH	$Ca(OH)_2$	pH	$CaSO_4$ NaOH
Chrys'm...	4.54	.1041	4.38	.1082	6.29	.0615	--	--
Carnation.	4.60	.0705	4.82	.1318	6.60	.0340	--	--
Barley....	4.33	.0422	4.34	.0404	6.45	.0582	5.50	.0466
Dianthus..	4.36	.0746	4.63	.0633	6.25	.0166	--	--
Endive....	4.63	.0202	4.65	.0791	6.60	.1187	6.52	.0439
Timothy...	4.56	.0058	4.59	.0248	6.32	.0291	5.26	.00145

The increased magnesium in the leafy crops--Chrysanthemum, Carnation, Dianthus and Endive--is explained on the basis of the magnesium being a part of the chlorophyll molecule. The leafy crops, therefore, contain more magnesium than Barley and Timothy.

ENDIVE AS AFFECTED BY SOIL AMENDMENTS

pH:6.52	6.32	4.65	4.63
$CaSO_4$	$Ca(OH)_2$	$CaSO_4$	Check
NaOH			

In four cases, as the data in Table VIII indicate, there is an increased percentage of iron in the calcium hydroxide series as compared with the check series. Chrysanthemum and Barley show the reverse.

Table VIII.

Percentage of Iron in Plant Tissue

	Series I.		II.		III.		IV.	
	pH	Check	pH	$CaSO_4$	pH	$Ca(OH)_2$	pH	$CaSO_4$ NaOH
Chrys'm...	4.54	.083	4.38	.080	6.29	.0498	--	--
Carnation.	4.60	.015	4.82	.058	6.60	.071	--	--
Barley....	4.33	.023	4.34	.087	6.45	.0079	5.50	.043
Dianthus..	4.36	.050	4.63	.448	6.25	.304	--	--
Endive....	4.63	.038	4.65	.034	6.60	.048	6.52	.040
Timothy...	4.56	.009	4.59	.036	6.32	.025	5.26	.032

The results of the calcium sulphate series and the calcium hydroxide series show that Carnation and Endive contained a smaller percentage of iron in the calcium sulphate series. Chrysanthemum, Barley, Dianthus and Timothy, however, show an increase with calcium sulphate.

Willis (17) states: "A comprehensive study of the experimental data concerning the availability of iron by different liming levels shows many gaps in the knowledge of the subject that can only be bridged by assumptions, some of which are rather weakly supported by evidence."

Mann (15) supports the results obtained in Table VIII, insofar as four of the plants show an increase in iron with increased alkalinity.

Again Willis (19) states that there is evidence that with increasing pH values, the soil becomes more reductive. It may follow then that iron of the soil might be converted to the more soluble ferrous form as a consequence of liming. To substantiate this, Carr and Brewer (20) have shown that ferric iron is precipitated as the hydroxide at pH 5.5, whereas the precipitation of ferrous hydroxide commences at pH 6.6 and is not complete until pH 7.9 is reached.

Table IX.

Total Grams of Iron Absorbed

	Series I.		II.		III.		IV.	
	pH	Check	pH	$CaSO_4$	pH	$Ca(OH)_2$	pH	$CaSO_4$ NaOH
Chrys'm.....	4.54	.0045	4.38	.0050	6.29	.0018	--	--
Carnation...	4.60	.0015	4.82	.0047	6.60	.0078	--	--
Barley......	4.33	.0020	4.34	.0005	6.45	.00047	5.50	.0021
Dianthus....	4.36	.0026	4.63	.0026	6.25	.00066	--	--
Endive......	4.63	.00018	4.65	.0017	6.60	.0056	6.52	.0019
Timothy.....	4.56	.00009	4.59	.0018	6.32	.0006	5.26	.0005

In respect to total iron absorbed, Table IX shows that Carnation, Barley, Endive and Timothy have more total iron in the calcium hydroxide series than in the check series.

A comparison of the calcium hydroxide and the calcium sulphate series shows that in three cases, more total iron was absorbed in the calcium sulphate treated soils. There was no visual signs of chlorosis due to iron in any plants that were grown.

TIMOTHY AS AFFECTED BY SOIL AMENDMENTS

pH: 4.59*	6.32	5.26	4.56
$CaSO_4$	$Ca(OH)_2$	$CaSO_4$ NaOH	Check

* Average pH for growing season.

DISCUSSION OF RESULTS

Calcium in equivalent amounts, but with different cation association, results in many inconsistencies with the plants grown, both in dry weight and in chemical composition. Tables I, II, and III show that Endive and Timothy are probably most affected by the absence of calcium.

In the calcium sulphate treated soils, there was normal growth of these two plants. It is reasonable to assume that calcium was responsible for the increases. It is also probable that the beneficial effect of growth in Series II is due to the sulphate ion. It is doubtful that the soil was so deplete in sulphur as to make such an increase over the check. This points to the significance of calcium in its function as the element in the plant's activities rather than that of reducing the hydrogen-ion concentration of the soil. This holds for all of the plants grown, with the exception of Chrysanthemum.

Another observation that is very clearly defined is the relation of the calcium content of the plants to the treatment. The data on Table IV shows that in every instance calcium content increases with the pH of the soil medium. This fact has been proved (1), (5), (8), and it was expected to occur with this experiment. The important relationship, however, is the amount of calcium in plants when equivalent amounts are applied, one of which increases acidity, the other decreasing the acidity of the soil. With reference to Table IV, it will be seen that the pH for the calcium sulphate treated soils is about 4.5, and for calcium hydroxide, 6.5. The percentage of calcium is greater in every case with the calcium hydroxide treatment. This seems to indicate that the intensity of the soil reaction governs the availability of calcium.

Magnesium is closely associated with calcium chemically. However, the element does not seem to supplement calcium in the plant tissue. Chrysanthemum, Endive and Barley show increases in the percentage of magnesium, due to high pH levels in the calcium hydroxide series, as compared with the calcium sulphate series. The reverse relation is found in the other crops. It is impossible to make any conclusions with these data.

A little more general conclusion can be drawn from the data on iron in Table VIII. Here the percentage, in general, increases with an increase in pH. It is assumed that, at the pH values at which the soils were maintained in the calcium hydroxide series, iron is in the ferrous condition and is available to the plant. The pH of the check series renders the iron in the ferric form and is precipitated of ferric hydroxide. This assumption supports, in general, the results in Table VIII.

SUMMARY AND CONCLUSIONS

From a general survey of the results, a few facts stand out clearly. Of the three ions determined, calcium alone is consistent as to the total amount absorbed and the percentage of composition. Iron and magnesium show no consistency as to absorption of ions from treatments producing high acidity or low acidity, although it is possible to indicate trends.

The hydrogen-ion concentration seems to govern the absorption of calcium from a Cheshire sandy loam.

There is evidence that the use of calcium sulphate for some flowers and crops may be beneficial. It is possible that, with continued application, a residual effect may be harmful due, in part, to the acid accumulation that ultimately must result from the use of such material.

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